Areas of particular interest:

Study of Compound Semiconductor Native Oxides

A Roshko KA Bertness 50.81.52.B4378

Because of their ability to provide both electrical and optical confinement, native oxides of compound semiconductors have had significant impact on optoelectronic devices. In particular, their use as apertures in vertical-cavity surface emitting lasers has resulted in record low threshold currents and high efficiencies. However, AlGaAs layers undergo a relatively large contraction on oxidation, resulting in strain in adjacent GaAs layers. This frequently causes structures containing AlGaAs oxide layers to delaminate or fail. We invite proposals that focus on understanding the strain, stability, and microstructure of compound semiconductor native oxides ($Al_{1-x}Ga_xAs$ and other novel compositions). Potential areas of study include the oxide microstructure and concomitant strain as functions of growth parameters, oxidation parameters, and post oxidation processing. Samples with engineered strain that may relax during post growth oxidation and annealing may also be of interest. Methods of minimizing strain and maximizing reproducibility will be sought. Facilities available for the study include a state-of-the-art MBE system, scanning electron microscopy (SEM), field emission SEM, transmission electron microscopy, and high resolution x-ray diffraction.

Quantum Dot Morphology

A Roshko R Mirin KA Bertness 50.81.52.B4379

Quantum dots have attracted a great deal of interest because of their unique properties and possibilities for optoelectronic applications. However, control of dot density, composition, position, size and shape remain major obstacles for many device applications. We invite proposals to address these issues through an investigation of quantum dot morphology as a function of growth parameters, such as temperature, rate, thickness, and composition. Studies of the interrelations between these variables and strain state are also of interest. State-of-the-art molecular beam epitaxy with reflected high-energy electron diffraction, atomic force microscopy, high resolution X-ray diffraction and transmission electron microscopy are available for analyzing quantum dot distributions, heights,shapes, spacings and strain fields. Correlation with optical properties, such as photoluminescence, is also of interest. The work will contribute to a more complete understanding of quantum dot morphology, how it correlates with device performance, and how it can be controlled through the choice of growth conditions. It will also contribute to a larger effort at NIST on photon turnstiles and microcavities.

Photonic Crystals and Optical MEMS

R Mirin NA Sanford 50.81.52.B3901

Periodic arrays of dielectrics, metals, and semiconductors offer enormous potential for the realization of active and passive photonic bandgap crystals. Wavelength-scale periodic microstructuring can be used to create bands of allowed and forbidden optical propagation in direct analogy with well-established concepts of electronic bands in semiconductors. Photonic crystals may be used to control the rate of spontaneous emission of an active center by defining the allowed optical frequencies it may couple to—this may even be limited to a single optical mode. Line defects introduced into photonic crystals can produce three-dimensional waveguide structures exhibiting nearly zero loss with 90-degree bends. Various embodiments of photonic bandgap crystals are being considered which encompass oxide, semiconductor, ferroelectric, and ferromagnetic materials structured by methods of plasma deposition, epitaxial growth, wafer bonding, heterogeneous integration, and integration with optical MEMS. These structures are also envisioned to play a significant future role in advanced integrated optics for optical wavelength division multiplexing, high-speed modulators, and high-extinction switches.

Semiconductor Quantum Optics

R Mirin NA Sanford 50.81.52.B4380

We are developing a regulated source of single photons by fabricating a single photon turnstile with a single quantum dot. Our goals include spontaneous emission control and delivery of the individual photons to any other on-chip location through photonic crystal waveguides. Important technologies for this project include microcavities, microdisks, photonic crystals, and nonlinear optics. We invite experimental and/or theoretical proposals that can complement and expand on this ongoing effort. Available resources include epitaxial semiconductor growth, e-beam lithography, fabrication facilities, and finite difference time domain software for electromagnetic modeling.

Ultrafast Laser Technology for Optical Signal Processing and Optical Tomography, at Terahertz Technology

JB Schlager NA Sanford 50.81.52.B5191

We are performing studies of optical frequency synthesis and metrology for applications in ultrafast all-optical analog-to-digital conversion systems, materials characterization, and wavelength-division multiplexed systems. This work involves ongoing development and optimization of NIST's semiconductor-saturable-absorber, mode-locked, Er/Yb waveguide laser technology (1550 nm) in addition to the use of ultrafast optical parametric oscillators (1300 nm to 2000 nm). Studies of continuum generation using these sources are being pursued for applications in material studies and high-resolution tomography. New work is under consideration to examine optical properties of materials at terahertz frequencies.

Nanoscopic Wide-Bandgap Materials Characterization by CW and Ultrafast Nonlinear Optics

NA Sanford 50.81.52.B4766

Nonlinear optics provide unique methods of characterizing a wide variety of semiconductor, dielectric, and hybrid optoelectronic materials and interfaces. We are developing methods of nanoscopic two-photon spectroscopy and nonlinear optics for examining local structural and electronic properties of the wide-bandgap III-nitride alloy semiconductors. The techniques include ultraviolet (UV) second-harmonic generation in addition to cw and time-resolved, two-photon UV spectroscopy. We are particularly interested in the study of polytyping, inversion domains, and alloy segregation, spectroscopy on the scale of defect separation (roughly 100 nm), and ultrafast processes involving interactions with strong static polarization fields in these materials. The nonlinear spectroscopic results will be correlated with x-ray diffraction imaging and high-resolution cathodoluminescence.

In-Situ Metrology of Epitaxial Crystal Growth for Semiconductor Optoelectronics

KA Bertness RK Hickernell 50.81.52.B1560

Semiconductor optoelectronic devices are being employed in a variety of applications, including telecommunications, computer interconnects, data storage, display, printing, and sensor systems. Most of these devices rely on accurate, reproducible epitaxial crystal growth; however, further reductions in growth cost will require further development of *in situ* and *ex situ* measurement tools. Our research focuses on optical *in situ* material probes (i.e., pyrometry, atomic absorption spectroscopy, and broadband normal-incidence optical reflectance) correlated with reflectance high-energy electron diffraction, *ex situ* x-ray diffractometry, photoluminescence spectroscopy, optical reflectance, and extensive modeling capabilities. Other resources include in situ mass spectrometry, atomic force microscopy, transmission electron microscopy, electrochemical profiling, and clean room facilities for processing test and device structures. We also examine the practical utility of various measurement tools through the growth of device structures, with emphasis placed on vertical-cavity surface-emitting lasers, in-plane lasers, quantum dot lasers, and saturable Bragg absorbers.

High Speed Optoelectronics Measurements

PD Hale TS Clement DF Williams 50.81.52.B4008

Increasing data rates and bandwidths of optical telecommunications, cable television systems, remote microwave antenna links, and computer data interconnections all require advanced techniques for accurately determining optical transmitter and receiver frequency response in both magnitude and phase. Methods being investigated at NIST include heterodyne and ultrashort pulse technologies. Current research focuses on fully calibratable measurement of frequency response with low uncertainty, extension of measurements to 110 GHz in the near future, and extension to 400 GHz in the next five years. We are especially interested in the measurement of response phase to 110 GHz or more with low uncertainty using high-speed sampling techniques and in methods for verifying these measurements. Future calibration artifacts will require fabrication of ultrafast photodetectors.

High-Speed Optical Receivers and Optoelectronic Integrated Circuits

PD Hale TS Clement RP Mirin DF Williams 50.81.52.B4767

The need for ever smaller size and increased bandwidth of optoelectronic devices is requiring these devices to be packaged in hybrid modules and optoelectronic integrated circuits. Characterization of the frequency response and electrical properties of these devices requires a change in measurement strategy away from coaxially connected modular devices to on wafer measurements. We are developing a new fully calibratable on-wafer measurement paradigm for calibrating optoelectronic and electronic devices. We are interested in fabricating new high-speed receivers that will be used as calibration artifacts in this new measurement strategy. Possible designs might include metal-semiconductor-metal photoconductive switches or p-i-u photodiodes grown in low-temperature GaAs or InGaAs. The work will result in artifacts that will be used to calibrate high-speed electronic probes.

Ultrashort Optical Pulse Characterization for High-Speed Measurements

TS Clement PD Hale 50.81.52.B4381

Femtosecond lasers are currently being used in the metrology of high-speed optoelectronic devices. We need to develop accurate methods of characterizing the femtosecond laser pulse amplitude and phase, as well as jitter noise on a train of ultrashort pulses. Increasingly stringent requirements in modern optoelectronic systems require waveform characterization over five decades in the frequency domain. The pulses need to be characterized with high dynamic range (in magnitude and in time) to detect pedestals and other aberrations. Pulse jitter and phase noise also affects many applications, including optical sampling and communications network synchronization, and may need to be characterized to levels as low as 10 fs. The well-characterized pulses will be used as a source for optical receiver measurements, as a characterization pulse for electro-optic sampling of high-speed circuits and transmission lines, and for characterizing optical waveforms that are modulated at very high speeds. We are especially interested in increasing the bandwidth of frequency-response measurements to >110 GHz, where it will become necessary to de-convolve the effect of the optical pulse from the rest of the measurement.

Waveform Metrology

Paul Hale TS Clement 50.81.52.B5521

Current techniques used by industry for characterizing digital waveforms are only qualitative at best. As a result, the specifications for test equipment and communication systems are conservative and are not well understood. In particular, the computer and communications industries both need measurements of different types of jitter and intersymbol interference in optical and electrical signals. For example, either of these effects could cause erroneous bit transmission leading to system inefficiencies. We have developed a world-class capability for calibrating equipment used in the acquisition of high-speed waveforms. We are looking for proposals that will investigate calibrated waveform measurement and the quantitative study of waveform metrics that characterize parameters such as random jitter, intersymbol interference, and eye margin.

Modeling and Simulation of High-Speed Optoelectronic Devices

PD Hale 50.81.52.B4768

The bandwidth revolution in optical communications relies on high-speed photodetectors, lasers, modulators, and amplifiers. We invite proposals in the area of modeling and simulation of all types of high-speed optoelectronic devices used in communications and metrology, high-speed measurements, and material properties modeling which supports device and measurement models. While all aspects of modeling are important to our efforts, we are particularly interested in the modeling of the modulation characteristics of these devices and the comparison with measurements. Other important measurements include spectral response, frequency response, temporal dynamics, quantum efficiency, bandwidth-efficiency product, saturation properties, and noise and microwave characteristics. Data analysis techniques which support high-speed and vector network measurements are also of interest.

Deep Ultraviolet Laser Metrology

CL Cromer ML Dowell 50.81.52.B1563

In recent years, ultraviolet (UV) laser—specifically excimer lasers—have found increased use in a variety of industrial and medical applications. For example, the most recent generation of optical lithography tools employ KrF (248 nm) excimer lasers for manufacturing computer chips with features sizes below 0.2 μm. Future generations will incorporate ArF (193 μm) and F2 (157 nm) excimer lasers as the semiconductor community pushes towards sub-0.1 μm features sizes. In addition, ArF excimer lasers are utilized in photorefractive keratectomy and laser-assisted stomal in-situ keratomileusis procedures for vision correction. Accurate measurements of laser pulse energy, total dose energy, and laser beam profile are critical in all of these applications. Furthermore, accurate materials characterization procedures are necessary to improve, model, and monitor tool performance. Our work includes the development of high-accuracy UV primary and transfer standard detectors, beam profile characterization, laser power, energy and dose measurement services, as well as accurate measurements of UV transmittance, birefringence, and long-term stability of various UV-grade optical materials.

Chromatic Dispersion Metrology
PA Williams 50.81.52.B4770
In optical telecommunications systems, chromatic dispersion (CD) causes the optical data pulses to spread in time, limiting the data transmission rate. This is dealt with by tailoring the waveguide dispersion of the transmission fiber or by adding a compensating element of opposite dispersion at the end of the transmission link. Compensating elements can have spectrally narrow group delay features that are important but difficult to measure. Typical CD measurement systems are based on a radio frequency phase shift technique or low-coherence interferometry. We invite proposals on such topics as improvements to existing CD measurement techniques (accuracy or resolution improvements), new measurement techniques, or development of fundamental dispersion standards (for example, using molecular absorption lines to give a theoretically predictable dispersion).

Polarization-Mode Dispersion Metrology
PA Williams 50.81.52.B4771
Polarization-mode dispersion (PMD) in fibers and components continues to be a critical parameter in optical telecommunications systems, particularly as data rates approach 40 Gigabits per second. PMD is a polarization-dependent group delay caused by birefringence and results in spreading of optical pulses in a way that doesn't allow passive compensation. The statistical nature of PMD makes it a complex (but interesting) topic with many measurement subtleties. Most recently, issues of active compensation and emulation as well as higher-order effects require improvements in PMD metrology. We solicit proposals on such topics as improvement to PMD measurement techniques (better spectral and temporal resolution), studies of the interactions of PMD with other parameters such as polarization-dependent loss, and metrology in support of PMD compensation.

Polarization Metrology for Optical Telecommunications
PA Williams 50.81.52.B4772
As optical telecommunication data rates increase and wavelength division multiplexed channel densities grow, polarization effects in the fiber channel and components become important. These effects include polarization-dependent loss (PDL), polarization-dependent gain (PDG), polarization-dependent wavelength shift (PDW), and polarization-mode dispersion (PMD). These parameters can cause signal and noise power variations or pulse distortion, resulting in increased bit error rate. We invite proposals concerning the topics of fundamental polarization metrology (measurement of retardance, diattenuation, and depolarization); improvements to characterization of PDL, PDG, PDW, and PMD; techniques of actively monitoring polarization state in transmission systems; or fundamental polarization references (artifacts giving theoretically predictable polarization parameters).

Low-Coherence Interferometry for Fiber Optic and Component Metrology
SD Dyer 50.81.52.B4773
Low-coherence interferometry is a valuable technique for measuring the dispersion and spectral characteristics of optical fiber and components. We are interested in applying low-coherence interferometry to the measurement of other characteristics such as polarization-mode dispersion and polarization-dependent loss. We are also interested in improvements that will enable us to obtain spatially resolved measurements of dispersion, polarization-mode dispersion, and other characteristics. This would be particularly valuable for characterizing components that consist of multiple elements; using low-coherence interferometry we can determine the contributions of each individual element in the device. Other potential new areas of research include the application of low-coherence techniques to the characterization of novel fibers and components, such as holey fiber, and to the characterization of active elements such as erbium fiber amplifiers, Raman amplifiers, and semiconductor optical amplifiers.

Fiber Optic Sensor Metrology
SD Dyer 50.81.52.B5522
Fiber optic sensors are lightweight, tiny, and flexible, with low power requirements and large dynamic range. They can detect a variety of measurands, including strain, temperature, pressure, and electromagnetic quantities. Much of our research on this topic is focused on fiber Bragg gratings (FBGs) for strain, temperature, and pressure sensing. We are interested in developing high-accuracy wavelength measurements for sensor calibration. Hysteresis and non-linearity due to the FBG's polymer coating and adhesives affects sensor calibration, so we are also interested in novel measurement techniques to characterize these effects. Other important topics include techniques for distributed sensing with high-spatial resolution, and understanding and improving the process of writing Bragg gratings in optical fibers.

Nonlinear Properties of Optical Fiber and Components
NR Newbury 50.81.52.B4774
As the capacity of communication systems increases both through higher bit rates and an increased use of wavelength division multiplexing, optical nonlinearities are becoming increasingly important. These nonlinearities can be both detrimental and beneficial to the system performance. Self-phase modulation, cross phase modulation, or four-wave mixing can limit system performance, while Raman amplification or intentional wavelength conversion through four-wave mixing can enhance system performance. We invite proposals for new methods for characterizing and exploring these nonlinear effects. Examples include developing basic metrology for the nonlinear coefficient n2, including its polarization and temporal properties, developing optical methods for characterizing the gain and noise properties of distributed Raman amplifiers, and exploring the characteristics and potential uses of highly nonlinear holey or photonic crystal fiber.

Supercontinuum Generation in Highly Nonlinear Optical Fiber
NR Newbury 50.81.52.B5523
A supercontinuum of light that spans over an octave in frequency can be generated by launching pulses from femtosecond lasers into highly nonlinear optical fiber. Through recently developed techniques, this supercontinuum can be phase-locked to a reference and thereby provide a stable frequency comb with a spacing equal to that of the laser repetition rate. These frequency combs have revolutionized optical frequency metrology since optical frequencies can now easily be measured relative to the time standard. We invite proposals that explore the generation, properties and applications of the supercontinuum. We are particularly interested in the generation of stable frequency combs in the telecommunications band that could be used for wavelength metrology. Other examples of proposals include developing a better understanding of the noise properties of the supercontinuum, and exploring other uses of the frequency comb related to LIDAR or optical coherence tomography applications.

Wavelength Standards for Optical Communications
SL Gilbert 50.81.52.B4775
Optical fiber communication systems are now incorporating wavelength division multiplexing (WDM); many wavelength channels in the near-infrared region can be transmitted on each optical fiber. Current WDM systems typically employ 50 or 100 GHz channel spacing (0.4 or 0.8-nm, respectively) in the 1540–1560-nm region; however, narrower channel spacing may be implemented soon. WDM will likely expand into other wavelength regions, possibly covering the entire range from about 1280 to 1630 nm. Wavelength standards are needed to set the absolute wavelength of these channels and avoid crosstalk. We invite proposals for the development of wavelength standards in the WDM region. Examples include high-accuracy standards for NIST internal calibration (possibly based on high-resolution spectroscopy and novel frequency comb techniques) and moderate accuracy standards that can be used by industry over broad wavelength regions.

Fiber Bragg Gratings and Ultraviolet Photosensitivity
SL Gilbert 50.81.52.B4776
Ultraviolet (UV) light can induce a permanent change in the refractive index of a glass material. This UV photosensitivity is very useful in fabricating novel integrated optic and fiber Bragg grating devices. Fiber Bragg gratings (wavelength-selective reflectors written into the core of optical fiber) are very useful as wavelength filters and dispersion compensators in the new wavelength division multiplexed optical fiber communication systems. They also make excellent strain sensors that can be networked to obtain distributed strain measurements of large structures, such as bridges and ships. Despite the development of numerous devices and techniques to control the phenomenon, a fundamental understanding of UV photosensitivity remains incomplete. We invite proposals on the study of UV photosensitivity or the development of new measurement methods for characterizing fiber Bragg grating devices.

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